Radiation Latchup Measurements of Calorimeter Circuits.

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Summary:
This paper documents radiation testing for latchup and single event upsets (SEUs) performed on electronic components that are candidates for use in the GLAST Calorimeter.

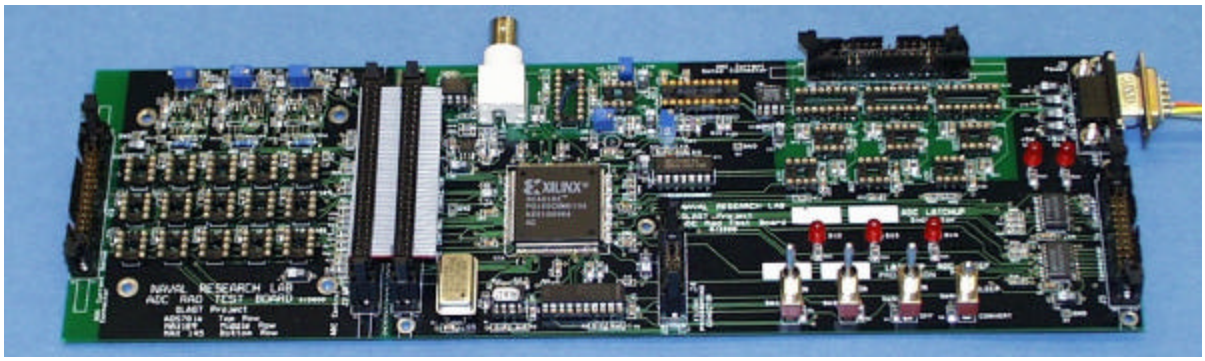
Introduction:
To complete initial parts selection for the GLAST calorimeter electronics, parts must be chosen that fit the system requirements but also have low latchup and SEU susceptibility. Critical components that fit the system requirements were radiation tested to further narrow down the list of possible choices.

Radiation testing has been performed by both pulsed laser testing and heavy ion testing. The tradeoffs between the two types of testing are as follows:
- Laser Radiation testing: Test setup is easier. Deposited energy values are not exactly known. Radiation can be pin-pointed to specific circuit region.
- Heavy ion testing: Physical effect is closer to the actual effect in space. Deposited energy is more understood. However pinpointing a particular circuit region in near impossible.

The laser radiation testing was performed at the NRL Radiation Effects Branch's Laser Radiation Facility and the heavy ion testing was performed at the Brookhaven Tandem Van de Graff SEU facility.

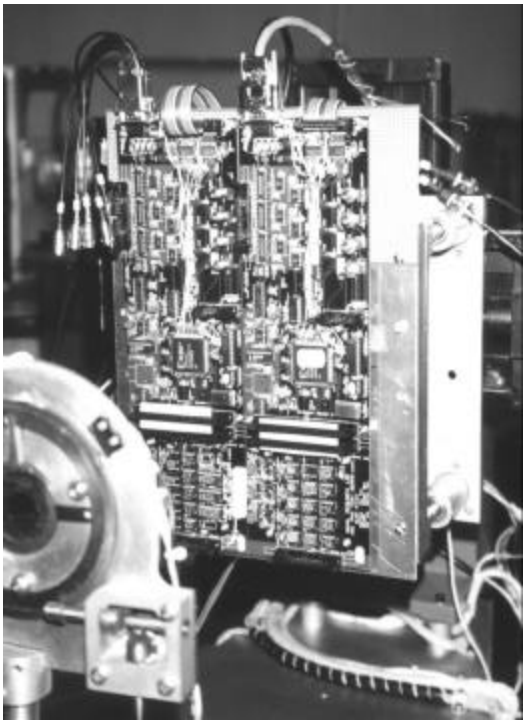
Setup:
The plastic chip packages were first decapsulated by an outside laboratory. For laser radiation testing, the chip under test is mounted in a test circuit board while an operator varies the chip position with respect to the laser focal point. A video monitor shares the same final focusing lens as the laser, giving good view of the circuit under the laser spot.

Figure 1 ADC Radiation Test Board. 3 rows of sockets for ADC chips are seen in the section to the left.



For the heavy ion testing, the decapsulated chip under test is mounted on a test board, which is mounted inside a vacuum chamber. An alignment laser is selectable to be centered in the beam tube for aligning the test chip to the beam axis. The accelerator control room controls the ion type delivered in the beam.

Figure 2 Two ADC Radiation Test Boards mounted at Brookhaven.



Laser Measurements:
Tested two types of ADCs were tested on 6/19/00, Burr-Brown ADS7816 and Maxim MAX189.
MAX189 at 5V operation, was latching at an equivalent LET of approximately 70 (MeV cm^2)/mg.
ADS7816 at 5V operation, was latching down to an equivalent LET between 15-20 (MeV cm^2)/mg.

Tested two new types of ADCs on 11/30/00, Maxim MAX1241 and Maxim MAX194.
MAX1241 at 5V operation, did not latchup, tested up to equivalent LET > 100 (MeV cm^2)/mg.
MAX194 at 5V operation, latched up at an equivalent LET between 70 and 80 (MeV cm^2)/mg.

Tested one type of ADC on 5/17/01, Analog Devices AD7475.
Tested two devices at 5V operation, both latched up at an equivalent LET between 35 and 40 (MeV cm^2)/mg.
There was a lot of metalization on the die, which could make the actual LET lower than the laser radiation number.

Tested one type of ADC, 9 DACs, and 6 Op-amps for latchup and single event upset, on 7/26/01.
ADC, Maxim MAX145 at 5V operation, no latchup, tested up to equivalent LET of about 150 (MeV cm^2)/mg.
ADC MAX189 at 5V operation, as calibration check, latched up between 53 to 60 LET. This checks approximately correct with previous laser measurements.

Digital to Analog Converters, monitored output voltage with hand-held meter to look for upsets.
Maxim MAX5131 at 3.3V operation, no latchups but output had perturbations, output always returned to normal voltage following removal of radiation. Tested up to equavelent LET of 600 (MeV cm^2)/mg.
Maxim MAX5133 at 3.3V operation, no latchups but output had perturbations, output always returned to normal voltage following removal of radiation. Tested up to equavelent LET of 1000 (MeV cm^2)/mg.
Maxim MAX5121 at 3.3V operation, no latchups but possibly fewer output perturbations, output always returned to normal voltage following removal of radiation. Tested up to equavelent LET of 900 (MeV cm^2)/mg.
Texas Instruments TLV5616 at 3.3V operation, no latchups but had some occurances of output stuck at wrong value. Tested up to equavelent LET of 800 (MeV cm^2)/mg.
Texas Instruments TLV5636 at 3.3V operation, no latchups but many occurances of output stuck at wrong value. Tested latchup up to equavelent LET of 800 (MeV cm^2)/mg. Measured single event upset sensivity to be approximately LET of 20 (MeV cm^2)/mg.
Linear Technology LTC1453 at 3.3V operation, latchup at equivalent LET of 5 (MeV cm^2)/mg.

Linear Technology LTC1659 at 3.3V operation, latchup at equivalent LET of 33 (MeV cm^2)/mg. Some small perturbations occurred in the output value, output stuck only occurred with latchup.
Analog Devices AD5320 at 3.3V operation, latchup at equivalent LET of 4 (MeV cm^2)/mg.

Operational Amplifiers, monitored output voltage of unity gain configurration.
Maxim MAX4251 at 3.3V operation, no latchups, test up to equivalent LET of 800 (MeV cm^2)/mg.
Maxim MAX495 at 3.3V operation, no latchups, some output perturbations, test up to equivalent LET of 800 (MeV cm^2)/mg.
Maxim MAX4123 at 3.3V operation, no latchups, test up to equivalent LET of 800 (MeV cm^2)/mg.
Texas Instruments TLV2461 at 3.3V operation, no latchup, test up to equivalent LET of 800 (MeV cm^2)/mg.
Burr-Brown OPA344 at 3.3V operation, no latchup, test up to equivalent LET of 800 (MeV cm^2)/mg.
Burr-Brown OPA336 at 3.3V, no latchup, test up to equivalent LET of 730 (MeV cm^2)/mg.

Ion Beam Measurements:

Five ADCs were tested at Brookhaven on March 14, 2001 by Jim Ampe and Steve Buchner of SFA/NRL.
ADS7816 quantity 5
MAX189 quantity 4 (1 decapsulated device did not function properly)
MAX145 quantity 5
MAX1241 quantity 5
MAX194 quantity 3

Two similar test boards held all the decapsulated chips and performed analog to digital conversions to a fixed reference voltage while in irradiation. When the test boards detected a latchup, counting of the particles stopped and the power supply to the ADCs was reset, clearing the latchup. All mounted chips were used for collecting radiation data. All chips of the same type exhibited similar radiation characteristics. Single event upsets were events in which the returned ADC value was outside the normal distribution by at least one ADC bin.

Formulas:
Latchup crossection = Number of latchups / Sum of particles
Latchup crossection error bar = SQRT(Num latchups) / Sum of particles
Upset crossection = Number of upsets / Sum of particles
Upset crossection error bar = SQRT(Num upsets)/ Sum of particles
Beam monitoring equipment computes number of particles from measured sample flux x time of gate open

Processed Data:

Device	MAX189	MAX189	MAX189
Ion, LET (MeV cm^2)/mg	Gold, 82.06	Iodine, 59.86	Bromine, 37.4
Sum of particles	4.5520E+06	1.1820E+06	2.9000E+06
Number latchups	1.2000E+01	3.0000E+00	0.0000E+00
Latchup crossection	2.6362E-06	2.5381E-06	0.0000E+00
Latchup error bar	7.6101E-07	1.4654E-06	0.0000E+00
Sum of particles	4.5520E+06	1.1870E+06	2.9000E+06
Number upsets	6.4000E+01	1.6000E+01	1.6000E+01
Upset crossection	1.4060E-05	1.3479E-05	5.5172E-06
Upset crossection error bar	1.7575E-06	3.3698E-06	1.3793E-06

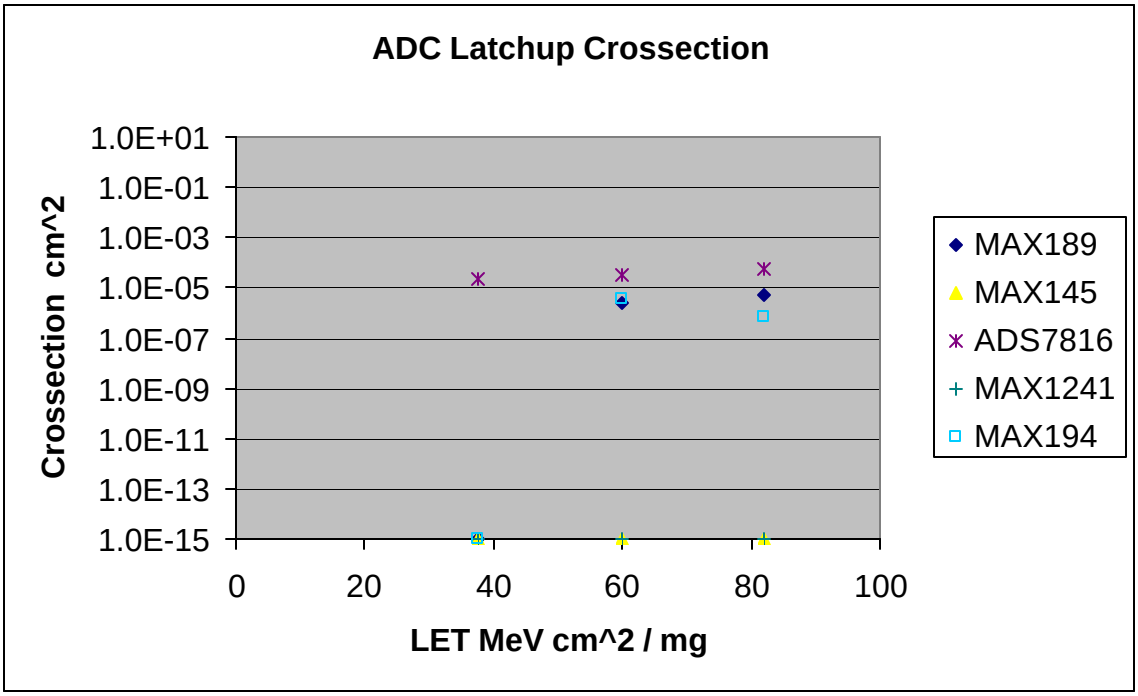
Device	MAX145	MAX145	MAX145
Ion, LET (MeV cm^2)/mg	Gold, 82.06	Iodine, 59.86	Bromine, 37.4
Sum of particles	2.2150E+06	6.2200E+05	3.6410E+06
Number latchups	0.0000E+00	0.0000E+00	0.0000E+00
Latchup crossection	0.0000E+00	0.0000E+00	0.0000E+00
Latchup error bar	0.0000E+00	0.0000E+00	0.0000E+00
Sum of particles	2.2150E+06	6.2200E+05	3.6410E+06
Number upsets	8.0000E+00	4.0000E+00	7.0000E+00
Upset crossection	3.6117E-06	6.4309E-06	1.9225E-06
Upset crossection error bar	1.2769E-06	3.2154E-06	7.2666E-07

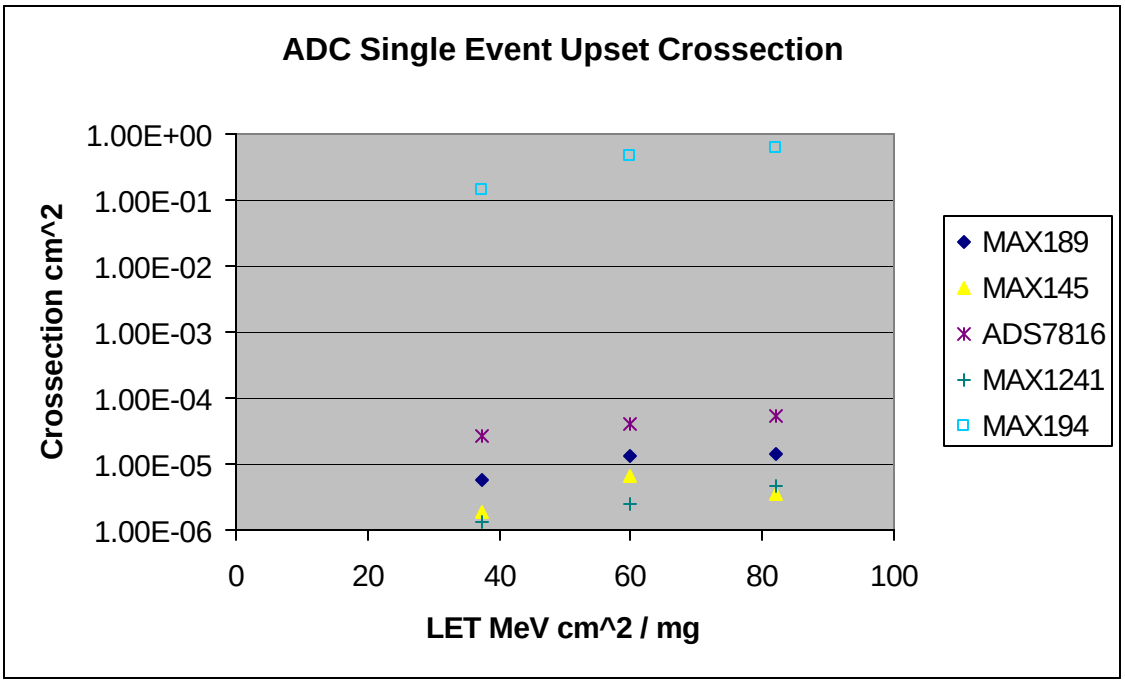
Device	ADS7816	ADS7816	MADS7816
Ion, LET (MeV cm^2)/mg	Gold, 82.06	Iodine, 59.86	Bromine, 37.4
Sum of particles	1.9200E+05	2.0000E+05	3.0700E+05
Number latchups	1.0000E+01	7.0000E+00	7.0000E+00
Latchup crossection	5.2083E-05	3.5000E-05	2.2801E-05
Latchup error bar	1.6470E-05	1.3229E-05	8.6181E-06
Sum of particles	1.6900E+05	2.0000E+05	3.0700E+05
Number upsets	0.0000E+00	1.0000E+00	1.0000E+00
Upset crossection	0.0000E+00	5.0000E-06	3.2573E-06
Upset crossection error bar	0.0000E+00	5.0000E-06	3.2573E-06

Device	MAX1241	MAX1241	MAX1241
Ion, LET (MeV cm^2)/mg	Gold, 82.06	Iodine, 59.86	Bromine, 37.4
Sum of particles	4.9680E+06	9.3280E+06	3.7300E+06
Number latchups	0.0000E+00	0.0000E+00	0.0000E+00
Latchup crossection	0.0000E+00	0.0000E+00	0.0000E+00
Latchup error bar	0.0000E+00	0.0000E+00	0.0000E+00
Sum of particles	4.9680E+06	9.3280E+06	3.7300E+06
Number upsets	2.3000E+01	2.3000E+01	5.0000E+00
Upset crossection	4.6296E-06	2.4657E-06	1.3405E-06
Upset crossection error bar	9.6534E-07	5.1413E-07	5.9948E-07

Device	MAX194	MAX194	MAX194
Ion, LET (MeV cm^2)/mg	Gold, 82.06	Iodine, 59.86	Bromine, 37.4
Sum of particles	1.5940E+06	8.7100E+05	2.1700E+06
Number latchups	1.0000E+00	3.0000E+00	0.0000E+00
Latchup crossection	6.2735E-07	3.4443E-06	0.0000E+00
Latchup error bar	6.2735E-07	1.9886E-06	0.0000E+00
Sum of particles	1.5940E+06	8.7100E+05	2.1600E+06
Number upsets	9.6840E+05	4.0967E+05	2.9578E+05
Upset crossection	6.0753E-01	4.7035E-01	1.3694E-01
Upset crossection error bar	6.1736E-04	7.3485E-04	2.5179E-04

Graphs:


ADC Latchup Crossection
Crossection cm^2
1.0E+01
1.0E-01
1.0E-03
1.0E-05
1.0E-07
1.0E-09
1.0E-11
1.0E-13
1.0E-15
0
20
40
60
80
100
LET MeV cm^2 / mg
MAX189
MAX145
ADS7816
MAX1241
MAX194


ADC Single Event Upset Crossection
Crossection cm^2
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
0
20
40
60
80
100
LET MeV cm^2 / mg
MAX189
MAX145
ADS7816
MAX1241
MAX194

Conclusion:
The Analog to Digital Converters that come out looking the best in terms of radiation induced latchup immunity are the MAX1241 and the MAX145. Neither ADCs had exhibited latchup under laser or ion beam radiation.

For Digital to Analog Converters, the MAX5121, MAX5131, MAX5133 look the best for both not latching and not experiencing an upset under high levels of laser radiation.

All Op-amps tested exhibited similar high levels of latchup immunity, and therefore all are good with regard to radiation latchup immunity.

Below is a summary of the radiation testing data.

Parameter	Max189	ADS7816	Max194	Max145	Max1241	AD7475
Smallest package	SO-16	MSO-8	SO-16	MSO-8	SO-8	MSO-8
Number of bit resolution	12 bit	12 bit	14 bit	12 bit	12 bit	12 bit
Operating voltage, Vdd, volts	4.5 – 5.5	4.5 – 5.5	+5 and -5	2.7 – 5.2	2.7 – 5.2	2.7 – 5.2
ADC clock	Internal	External	External	Internal or External	Internal	External
Input signal Range	0 to Vdd	0.1 to Vdd	0 to Vdd	0 to Vdd	0 to Vdd	0 to +2.5
Laser Test Latchup Threshold, LET (MeV* cm^2)/mg	~ 70	15 - 20	~70	> 150	>150	30 - 40
Ion Beam Latchup Threshold, LET (MeV * cm^2)/mg	~60	<< 40	< 40	> 80	> 80	
Ion Beam SEU Upset Threshold, LET (MeV * cm^2)/mg	~40	<< 40	<< 40	> 80	> 80	

Manufacturer	DAC Part No.	Supply Volt	Bits Resolution	Data Format	Laser Test Latchup Threshold, LET, (MeV * cm^2)/mg	Laser Test SEU Threshold. LET, (MeV * cm^2)/mg
Maxim	Max5121	3V	12	Serial	> 900	> 900
Maxim	Max5131	3V	13	Serial	> 600	> 600
Maxim	Max5133	3V	12	Serial	> 1000	> 1000
Texas Instruments	TLV5616	3V	12	Serial	> 800	< 800, not measured
Texas Instruments	TLV5636	3V	12	Serial	> 800	~20
Linear Technology	LT1453	3V	12	Serial	~5	
Linear Technology	LT1659	3V	12	Serial	~33	~33
Analog Devices	AD5320	3V	12	Serial	~4	

Manufacturer	Op-Amp Part No.	Supply Volt	Input Range	Output Range	Laser Test Latchup Threshold, LET, (MeV * cm^2)/mg
Maxim	Max4251	3 to 5V	Rail to Rail	Rail to Rail	> 800
Maxim	Max495	3 to 5V	Rail to Rail	Rail to Rail	> 800
Maxim	Max4123	3 to 5V	Rail to Rail	Rail to Rail	> 800
Texas Instruments	TLV2461	3 to 5V	Rail to Rail	Rail to Rail	> 800
Burr-Brown	OPA344	3 to 5V	Rail to Rail	Rail to Rail	> 800
Burr-Brown	OPA336	3 to 5V	Rail to Rail	Rail to Rail	> 730